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MECHANICAL PROPERTIES OF EXPERIMENTAL WELDS IN A633 GRADE E NORMALIZED HIGH-STRENGTH LOW-ALLOY STEEL FOR PIPELINE FITTINGS

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Welding Section

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ABSTRACT

Experimental submerged-arc welds were prepared in A633 Grade E steel typical of that used in pipeline fittings. Weld consumables, obtained from Oerlikon Corporation, were Fluxocord 43.1 and $SD_3$1Ni wires and OP41TT flux.

Mechanical properties of the welds were measured after a normalizing (900°C) and stress relief (650°C for 1 h) heat treatment. The welds prepared with the Fluxocord 43.1 wire and OP41TT flux achieved the required tensile properties with a yield strength of 519 MPa, an ultimate tensile strength of 616 MPa and an elongation of 29%.

All of the experimental welds failed to achieve the notch toughness requirement of 40 J at -50°C.

LABORATOIRES DE RECHERCHE EN MÉTALLURGIE PHYSIQUE

RAPPORT PRM/LRMP 83-23(TRO

PROPRIÉTÉS MÉCANIQUES DE SOUDURES EXPÉRIMENTALES DANS UN ACIER FAIBLEMENT ALLIÉ TRÈS RÉSISTANT NORMALISÉ A633, QUALITÉ E, DESTINÉ À LA FABRICATION DE RACCORDS DE PIPELINES

par

J.T. McGrath, M.W. Letts et J.A. Gianetto

RÉSUMÉ

On a préparé des soudures expérimentales à l'arc submergé dans un acier A633, qualité E, couramment utilisé pour les raccords de pipelines. Les produits de soudure, provenant de Oerlikon Corporation étaient les suivants: fils Fluxocord 43,1 et $SD_3$1Ni, et le fondant OP41TT.

On a mesuré les propriétés mécaniques des soudures après traitement thermique de normalisation (900°C) et de détente (650°C pendant 1 h). Les soudures préparées avec le fil Fluxocord 43,1 et le fondant OP41Tt présentaient la résistance à la traction requise, avec une limite élastique de 519MPa, une résistance à la traction maximale de 616 MPa et un allongement de 29%.

Aucune des soudures expérimentales ne présentait la résistance à l'entaille requise de 40J à -50°C.

1. INTRODUCTION

Welded pipeline fittings for use in high-pressure oil and gas pipelines that require a minimum yield strength of 415 MPa, an elongation of 23% and a notch toughness of 40 J at -50°C are usually manufactured from A633, Grade E steel. Following mechanical working (i.e., roll forming and extrusion) and welding operations, the fitting is subjected to a normalizing and stress-relief heat treatment.

Fittings fabricators have found difficulty in achieving the required mechanical properties in the submerged-arc welds in the body of the fitting after normalizing and stress relieving.

The objective of this program was to evaluate the mechanical properties of welds prepared in A633 Grade E steel using a range of currently available submerged-arc welding consumables.

2. EXPERIMENTAL PROCEDURE

2.1. Materials Selection

Two steels, 23 mm in thickness, of A633 Grade E specification were obtained from a Canadian and a Japanese manufacturer. The compositions of these steels are listed in Tables 1 and 2. In order to obtain similar properties to that of the base metal, the target values for the mechanical properties of the weld metal, in the normalized and stress-relieved condition, were 448 MPa yield strength, 588 MPa ultimate tensile strength, 25% elongation, and a Charpy impact energy of 40 J at -50°C.

Following discussions with various fittings fabricators, steel producers and consumable suppliers, two consumable combinations were selected to manufacture the submerged-arc welds. The Oerlikon Fluxocord 43.1 wire is a medium alloyed basic flux-cored wire containing additions of molybdenum, vanadium and nickel. The $SD_3$1Ni wire is alloyed with nickel. Both wires were used with Oerlikon OP41TT flux. This flux is classified as a basic type agglomerated flux with a low oxygen potential.

2.2. Weld Procedure

The weld preparation, shown in Fig. 1, was a butt joint with a single bevel 60° included angle, 3 mm band and 1.6 mm gap. Prior to welding, the joint was preheated to 125°C. This temperature was maintained through all

welding operations. The initial root pass was made by manual metal-arc welding. Two passes with an E 7018 electrode were used. The remainder of the joint was filled by submerged-arc welding. The manual passes in the root region were then removed by arc gouging and filled with two passes by submerged-arc welding. The welding parameters used in the preparation of the four weldments are listed in Tables 3 to 6.

The presence of a strong magnetic field in the steel plates resulted in a distortion of the welding arc during submerged-arc welding. This problem was partially overcome by demagnetizing the plates prior to welding.

The welds were subject to X-ray radiographic inspection. The results of this inspection indicated that there were no defects of significant size to cause rejection of the welds.

All welds were given a normalizing heat treatment of 900°C for 1 h, followed by stress relieving at 650°C for 1 h.

2.3. Microstructure and Mechanical Testing

The microstructure of the welds was evaluated in the as-welded and normalized and stress-relieved conditions. The transformation products were identified and the grain size of the normalized and stress-relieved structures were measured using standard optical metallographic techniques.

The tensile properties, i.e., yield and ultimate tensile strengths, and % elongation were measured for the normalized and stress-relieved welds. The tensile specimens were machined with their longitudinal axis parallel to the welding direction.

The notch toughness was assessed from Charpy impact tests performed over a range of temperatures on the as-welded and normalized and stress relieved weld metals. The specimens were taken from the 1/2 thickness position, with the notch in the through-thickness direction.

The hardness of the welds was determined from Vickers hardness measurements.

3. RESULTS AND DISCUSSION

3.1. Composition and Microstructure

The compositions of the weldments prepared with base metals A and B are listed in Tables 1 and 2 respectively. With reference to Table 1, it is noted that weld M_1 had significantly higher levels of nickel, molybdenum and

vanadium than base metal A. In addition, the carbon, silicon and niobium levels were much lower in the weld metal than in the base metal. Weld W_2 showed only a significantly higher level of nickel in comparison to the base metal A. The carbon, silicon, molybdenum, vanadium and niobium contents were much lower in the weld metal than in the base metal.

Similar compositional trends existed in the welds W_3 and W_4 prepared in base metal B (Table 2).

The microstructures of the four welds were all basically the same in the as-welded condition. The lower portion of each weld bead was composed primarily of acicular ferrite with some proeutectoid ferrite (Fig. 2 and 3). The upper region of the bead, which was reheated by the subsequent weld pass, contained fine, recrystallized ferrite grains.

The normalizing treatment resulted in a weld microstructure composed of homogeneous, polygonal ferrite grains with bands of spheroidized carbide particles. Examples of this microstructure for the four experimental welds are shown in Fig. 4 and 5.

3.2. Tensile Properties

The tensile properties of the four weld metals in the normalized and stress-relieved condition are listed in Table 7. Welds W_1 and W_3 produced in steels A and B with the Fluxocord 43.1 wire and the OP41TT flux surpassed the target values of yield and ultimate strength and % elongation (section 2.1). Welds W_2 and W_4 made with $SD_3$1Ni wire and OP41TT flux had sufficient ductility but were deficient in strength.

The hardness values for all of the welds in both the as-welded and normalized and stress-relieved conditions are contained in Table 8. In general, the welds made with the Fluxocord 43.1 wire and OP41TT flux had a higher hardness than those made with $SD_3$1Ni wire and OP4TT flux. Thus, the trend in weld hardness was similar to that shown for weld strength.

The higher strength and hardness exhibited by the normalized and stress-relieved welds made from the Fluxocord 43.1 wire and OP41TT flux is attributed primarily to the presence of nickel, molybdenum and vanadium found in welds W_1 and W_3 (Tables 1 and 2). Then nickel and molybdenum are probably in solid solution whereas the vanadium is present as vanadium carbo-nitride precipitate particles. Grain size was not a factor in accounting for differences in strength and hardness amongst the welds. The ferrite grain size was similar for all the welds in the normalized and stress-relieved condition.

3.3. Notch Toughness

The notch-toughness data for the welds in the as-welded and normalized and stress-relieved conditions are listed in Tables 9 and 10 respectively.

In the as-welded condition, welds prepared with the $SD_3$1Ni wire and OP41TT flux equaled or surpassed the notch toughness of welds made with Fluxocord 43.1 wire and OP41TT flux. As indicated in Section 3.1, all welds had a similar microstructure. The combination of acicular ferrite and recrystallized ferrite in the as-welded structure should provide good resistance to brittle fracture. The slightly lower toughness exhibited by welds W_1 and W_3 is caused by the higher strength provided by the addition of alloying elements molybdenum, nickel and vanadium.

The most important observation in examining the notch toughness data of the welds in the normalized and stress-relieved condition (Table 10) is that the target value of 40 J at -50°C was not achieved in welds W_1 and W_3 prepared with the Fluxocord 43.1 wire and OP41TT flux. Although the levels of notch toughness were high (>80 J) at -20°C, there was a sharp drop at -50°C. The target value of 40 J was reached in some tests on welds W_2 and W_4, but these welds did not have acceptable strength levels.

In reviewing the options available to improve the notch toughness of welds in the normalized and stress-relieved state, one can examine, in particular, the microstructural features of welds W_1 and W_3. The normalizing temperature of 900°C could be lowered slightly, but this is not likely to result in a significantly finer ferrite grain size which would be required to improve the notch toughness. Adjustments in the stress-relieving temperature and time may influence the formation, size and distribution of vanadium carbonitride particles. These precipitate particles, while beneficial in increasing the weld strength, are the main factor in reducing the notch toughness.

4. CONCLUSIONS

1. Welds in the normalized and stress-relieved condition, prepared with the Fluxocord 43.1 wire and OP41TT flux, achieved the required tensile properties with a yield strength of 519 MPa, an ultimate tensile strength of 616 MPa and an elongation of 29%.

2. All of the experimental welds, in the normalized and stress-relieved condition, failed to achieve the notch-toughness requirement of 40 J at -50°C.

3. In general, submerged-arc welds prepared with currently available welding consumables cannot achieve the required properties of 448 MPa yield strength and notch toughness of 40 J at -50°C, after a normalizing and stress-relief heat treatment.

Table 1. Base metal and weld composition.

Material	C	S	P	Si	Mn	Al	Sn	Cu	Ni	Cr	Mo	V	Nb
Base Metal A	0.16	0.007	0.015	0.300	1.40	0.03	0.01	0.175	0.175	0.06	0.12	0.08	0.035
Weld W_1*	0.06	0.015	0.020	0.125	1.25	0.01	0.009	0.095	1.69	0.063	0.29	0.13	0.005
Weld W_2**	0.08	0.015	0.020	0.190	1.21	0.01	0.015	0.210	1.18	0.061	0.035	0.01	0.005

*Prepared with Fluxocord 43.1 wire and OP41TT flux.

**Prepared with $SD_3$1Ni wire and OP41TT flux.

Table 2. Base metal and weld composition.

Material	C	S	P	Si	Mn	Al	Sn	Cu	Ni	Cr	Mo	V	Nb
Base Metal B	0.19	0.010	0.010	0.273	1.38	0.03	0.01	0.09	0.225	0.11	0.12	0.09	<0.005
Weld W_3*	0.06	0.015	0.015	0.132	1.33	0.015	0.002	0.108	1.765	0.072	0.31	0.135	<0.005
Weld W_4**	0.10	0.015	0.015	0.240	1.20	0.015	0.018	0.255	1.26	0.08	0.04	0.015	<0.005

*Prepared with Fluxocord 43.1 wire and OP41TT flux.

**Prepared with $SD_3$1Ni wire and OP41TT flux.

Table 3. Welding procedure for weld W_1.

Plate: Steel 'A'
Wire: 4 mm diam Fluxocord 43.1
Flux: OP41TT

Pass #	Current amps	Wire feed speed mm/s	Voltage volts	Travel speed mm/s	Elect. stickout mm	Heat input kJ/mm
1	520	22	32	8.5	32	2.0
2	520	22	32	7.7	32	2.2
3	540	22	33.5	6.8	32	2.7
4	540	22	32	6.8	32	2.6
Plate was demagnetized after pass #4.						
5→9	540	22	32	9.8	32	1.8
The plate was turned over, backgouged to a depth of 10 mm to remove root bead.						
10→13	520	17	30.0	8.5	32	1.8

Table 4. Welding procedure for weld W_2.

Plate: Steel 'A'
Wire: 4 mm diam $SD_3$1Ni
Flux: OP41TT

Pass #	Current amps	Wire feed speed mm/s	Voltage volts	Travel speed mm/s	Elect. stickout mm	Heat input kJ/mm
1	520	17	30.0	9.3	32	1.7
2	520	17	30.0	8.5	32	1.8
3	520	17	30.0	7.7	32	2.0
4>9	520	17	30.0	8.5	32	1.8
The plate was turned over, backgouged to a depth of 8 mm to remove root bead.						
10>11	520	17	30.0	7.7	32	2.0
12	520	17	30.0	8.5	32	1.8

Table 5. Welding procedure for weld W_3.

Plate: Steel 'B'
Wire: 4 mm diam Fluxocord 43.1
Flux: OP41TT

Pass #	Current amps	Wire feed speed mm/s	Voltage volts	Travel speed mm/s	Elect. stickout mm	Heat input kJ/mm
1	520	22	32	8.5	32	2.0
2.	520	22	32	7.7	32	2.2
3→4	520	22	32	6.8	32	2.5
5→7	520	22	32	9.8	32	1.7
The plate was turned over and backgouged to a depth of 6 mm to remove root bead						
8	520	22	32	9.8	32	1.7
9	520	22	32	7.7	32	2.2

Table 6. Welding procedure for weld W_4.

Plate: Steel 'B'
Wire: 4 mm diam $SD_3$1Ni
Flux: OP41TT

Pass #	Current amps	Wire feed speed mm/s	Voltage volts	Travel speed mm/s	Elect. stickout mm	Heat input kJ/mm
1	500	17	30.0	9.3	32	1.6
2➤7	500	17	30.0	8.5	32	1.8
The plate was turned over and backgouged to a depth of 6 mm to remove root bead						
8	500	17	30.0	8.5	32	1.8
9	500	17	30.0	7.7	32	2.0

Table 7. Tensile properties of experimental welds in the normalized and stress-relieved condition.

Weld	Yield strength MPa	Ultimate strength MPa	Elongation %
W_1	519 500	620 620	29 28
W_2	387 403	512 508	35 33
W_3	518 527	606 610	30 29
W_4	390 406	503 520	34 33

Table 8. Hardness values of weldments.

Material	Hardness	
	As welded, VHN	Normalized and stress relieved, VHN
Base metal A	-	195
Weld W_1	252	219
Weld W_2	226	165
Base metal B	-	210
Weld W_3	248	218
Weld W_4	217	165

Table 9. Charpy impact energy for welds in as-welded condition.

Weld	CVN Impact energy, J			
	-50°C	-20°C	0°C	25°C
W_1	25	65	112	133
	46	56	94	110
	25			
W_2	87	146	151	167
	110	123	154	157
	22	128		
W_3	27	71	98	122
	45	64	106	109
	38			
W_4	34	80	112	135
	32	95	132	168
	35			

Table 10. Charpy impact energy for welds in normalized and stress-relieved conditions.

Weld	CVN Impact energy, J			
	-50°C	-20°C	0°C	25°C
W_1	12	65	59	127
	16	112	110	158
	9			
W_2	120	179	277	188
	7	135	305	299
W_3	11	110	135	164
	11	100	144	146
	8			
W_4	108	127	251	285
	8	140	168	282
	46			

Fig. 1 - Macro section of typical weldment indicating weld pass sequence and joint geometry. (X3). (neg 8249)

Fig. 2(a) - As-welded microstructure, weld W_1. (X500). (neg 8179)

Fig. 2(b) - As-welded microstructure, weld W_2. (X500). (neg 8180)

Fig. 3(a) - As-welded microstructure, weld W_3. (X500). (neg 8181)

Fig. 3(b) - As-welded microstructure, weld W_4. (X500). (neg 8182)

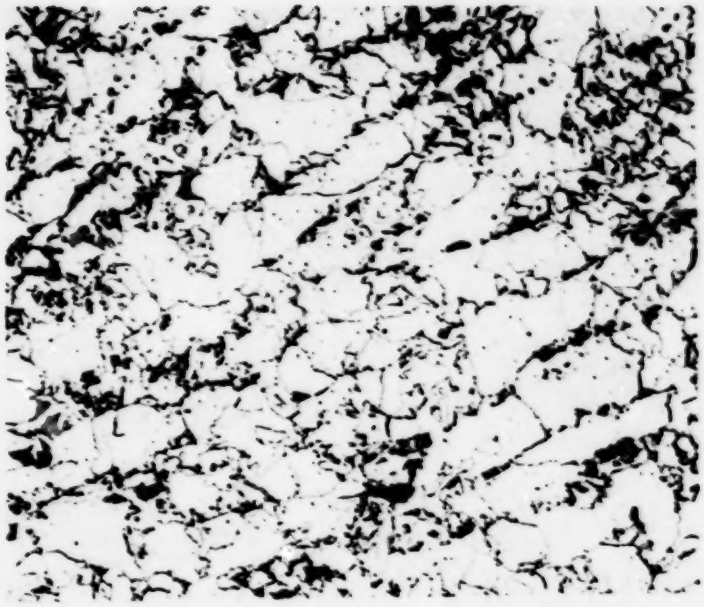

Fig. 4(a) - Microstructure of weld W_1 in the normalized and stress-relieved condition. (X500). (neg 8183)

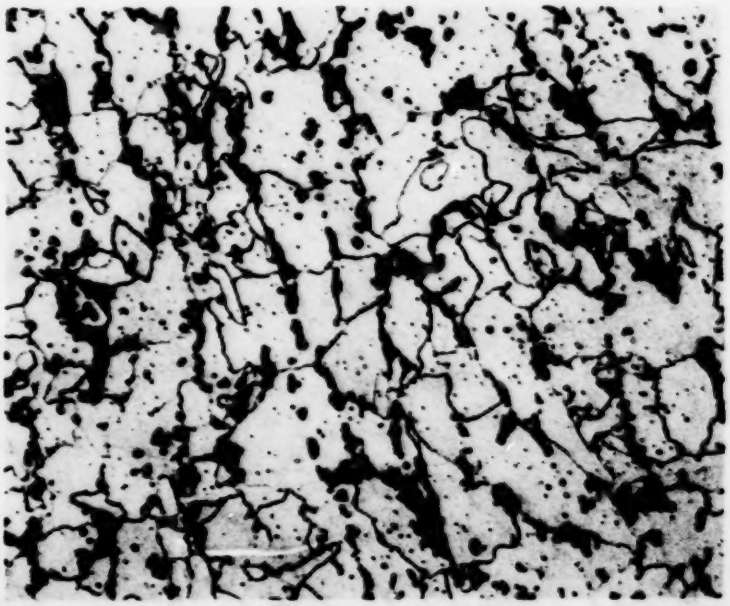

Fig. 4(b) - Microstructure of weld W_2 in the normalized and stress-relieved condition. (X500). (neg 8184)

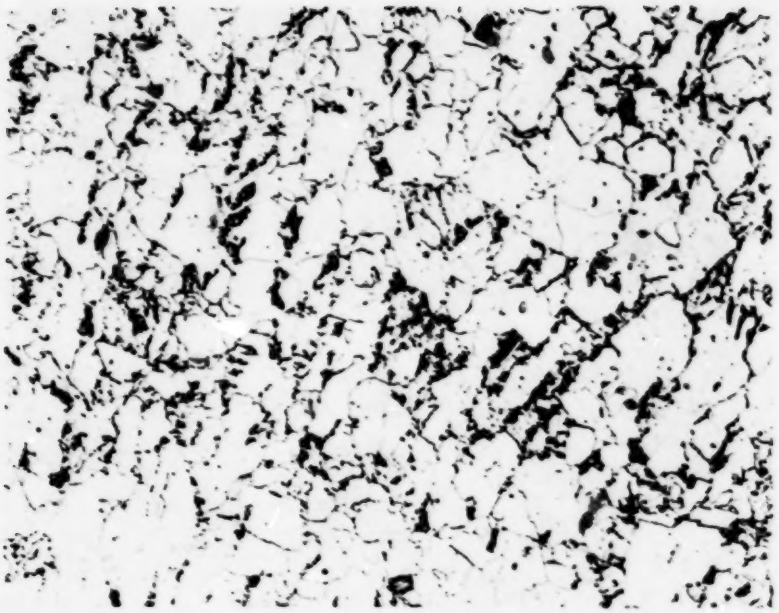

Fig. 5(a) - Microstructure of weld W_3 in the normalized and stress-relieved condition. (X500). (neg 8185)

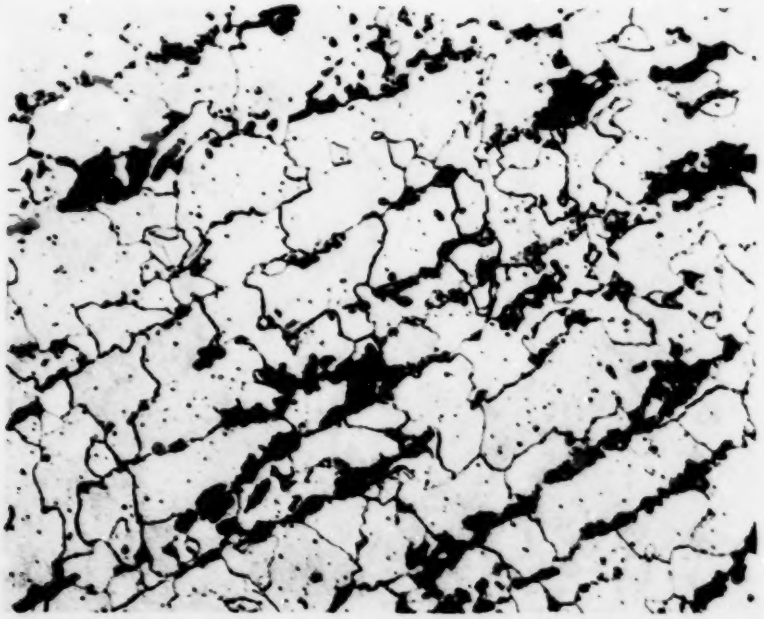

Fig 5(b) - Microstructure of weld W_4 in the normalized and stress-relieved condition. (X500). (neg 8186)

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